N91-32637

FD-TD CALCULATION WITH COMPOSITE MATERIALS. APPLICATION TO C160 AIRCRAFT MEASUREMENTS.

J.C. Alliot*, J. Grando*, F. Issac* and X. Ferrières**

*Office National d'Etudes et de Recherches Aéropatiales,
B.P. 72, 9232 CHATILLON CEDEX, FRANCE

**SLX Informatique, 1 Place Charras, 92400 COURBEVOIE, FRANCE

ABSTRACT

In a frequency domain in which a material thickness is smaller than the skin depth, a formalism based on the sheet impedance concept has been developed and introduced in the FD-TD code ALICE. The predictive capabilities of the 3D code have been evaluated by comparison to analytical and experimental data.

1. INTRODUCTION

For large structures such as aircraft, the spatial resolution of 3D computer codes is insufficient to model thin surfaces such as lossy skins. There is therefore a need to accurately include their effects on the electromagnetic coupling paths and so, to define an approach whereby lossy surfaces can be treated in the time-domain. This can be achieved by defining a relationship between the surface electric and magnetic fields such that the details of the skin do not have to be directly modelled. In a frequency domain in which a material thickness is smaller than the skin depth, a formalism based on the sheet impedance concept has been developed and introduced in the FD-TD code ALICE [1]. The predictive capabilities of the 3D code have been evaluated by comparison to analytical results obtained by K.F. Casey [2] on a loaded aperture and by comparison to experimental data obtained during an in-flight experiment conducted in France to study lightning interaction with a vehicle [3].

2. LOW FREQUENCY ELECTROMAGNETIC PENETRATION OF LOADED APERTURES

In a frequency domain in which a material thickness is smaller than the skin depth, it can be shown [4] that a lossy material may be characterized by its sheet impedance defined as:

$$Z_s = \frac{\vec{E}}{\vec{J}_s} \qquad (1)$$

where $\vec{J}_s$ is the surface current density and $\vec{E}$ is the tangential electric field component.

For good conductors in which displacement currents are negligibly small compared with conduction currents for the frequency of interest ($\sigma \gg \varepsilon\omega$), equation (1) reduces to:

$$Z_s = \frac{1}{\sigma d} \tag{2}$$

where σ and d are the material conductivity and thickness respectively.

The Magnetic Shielding Effectiveness (MSE) of a structure is defined as:

$$MSE = \left| \frac{\vec{H}}{\vec{H_o}} \right| \tag{3}$$

where $\vec{H_o}$ is the field at a point chosen in the absence of the shield and $\vec{H}$ is the field at the same point with the shield in place.

K.F. Casey [2] has shown analytically that the MSE of a circular aperture (of radius a) loaded by a panel characterized by its sheet impedance Z_s is given, in the frequency domain, by:

$$MSE = F_1 \left\{ 1 + j \frac{F}{2F_{co}} \frac{2 - \frac{F_c}{F_{co}}}{\frac{F_c}{F_{co}}} F_1 \right\}^{-1} \tag{4}$$

with:

F: frequency in Hz

$$F_{co} = \frac{3\,Z_s}{8\,\mu_o\,a} \tag{5}$$

$$F_c = F_{co} \left[1 + \frac{RL}{Z_s\,a} \right] \tag{6}$$

R: the net resistance of the joint (length L) located around the panel.

F_1 is obtained by solving the linear system $F_m + \frac{\beta}{\pi} \sum K_{mn} F_m = S_{m,1}$ where $\beta = j \frac{3\pi}{8} \frac{F}{F_{co}}$ and K_{mn} is a combination of m and n index.

When the junction between the panel and the metallic plane is perfect (R = 0), equation (4) reduces to:

$$MSE = \frac{1}{1 + j\dfrac{F}{F_c}} \qquad (7)$$

This expression corresponds to a first order filter function with a cut-off frequency $F_c = F_{co}$ for 3 dB attenuation.

3. FD-TD MODELLING

If we consider a composite sheet in the plane OXY of a unit cell (figure 1), it can be shown [5] that the current density $\vec{J}$ may be expressed as:

$$\vec{J} = \frac{1}{Z_s \Delta z} \vec{E} \qquad (8)$$

With this expression for $\vec{J}$, equation (2) in reference [1] can be solved in finite difference form without taking into account the panel thickness.
Assuming that the contact resistance around a panel corresponds to a joint of width W, we can define a surface impedance of this joint as:

$$Z_j = \frac{RL}{W} \qquad (9)$$

The expression (6) for F_c then becomes:

$$F_c = F_{co}\left[1 + \frac{W}{a}\frac{Z_j}{Z_s}\right] \qquad (10)$$

In the FD-TD code, W will be the mesh size.
The joint surface impedance Z_j can be related to a conductivity σ_j and a thickness d_j so that $Z_j = (\sigma_j d_j)^{-1}$.

4. COMPARISON TO ANALYTICAL RESULTS

The structure used to study field penetration through a loaded aperture is a perfectly conducting cavity having a square aperture on the upper side (figure 2). The aperture dimensions are small compared to the cavity size. The box is connected to two thin wires of infinite extend in space. A current generator is located on one of them at 5.3 m from the cavity. The waveform of the injected current is of trapezoidal shape with a rise time of 2 ns and a peak value of 1000 A. In a first step, the joint around the panel will be considered as perfect (R = 0).

Figure 3a shows the waveform of the magnetic field component H_o computed at a point P (figure 2) in the case of a free aperture.

The point P is located inside the cavity, 5 cm below the aperture. As indicated by the FFT of H_o shown in figure 3b, the high frequency content is mainly due to a $\lambda/4$ resonance of wire 1 (between the current generator and the box - F = 15 MHz) and to a $\lambda/2$ resonance of the cavity (F = 45 MHz).

Figures 4a and 5a show the temporal waveforms of the magnetic field component H computed at the point P when the aperture is loaded with a composite panel having a sheet impedance of 1 Ω and 0.1 Ω respectively. A low frequency content appears as a consequence of the panel filtering effect.

Figures 4b and 5b show the FFT ratios for the magnetic field components H and H_o corresponding to the previous results. The agreement with the theory presented in § 2 is excellent. The code has predicted:

- The same low frequency content for H_o and H.
- The cut-off frequency corresponding to a 3 dB attenuation (7),(5). An equivalent radius "a" of the square aperture can be calculated by comparison to a circular aperture having the same area. Using (5) with a = 0,3 m, we obtain F_c = 1 MHz for Z_s = 1 Ω and F_c = 0.1 MHz for Z_s = 0.1 Ω.
- The decrease of the spectrum with a slope of 20 dB/decade for $F \gg F_c$ as indicated by (7).

We consider, now, that there is a joint all around the panel. Two values Z_j = 2.5 Ω and Z_j = 22.5 Ω have been considered. These values have been chosen to satisfy F_c/F_{co} = 2 and F_c/F_{co} = 10. With the contact length L = 2 πa, the corresponding contact resistances are R = 0.16 Ω and R = 1.43 Ω respectively. From (5), the theoretical cut-off frequency for a loading material having a sheet impedance Z_s = 1 Ω is F_{co} = 1 MHz.

Figures 6 and 7 show the variation of the MSE given by (4) and (7) and also the variation of the MSE obtained with the FD-TD code using W = 0.12 m: H_o and H are the magnetic field components computed on the axis of the aperture, 15 cm inside the cavity, in the case of a free aperture and in the case of a loaded aperture with a joint, respectively. For R = 0.16 Ω, the approximate expression (7) is close to the exact value given by (4) and the FD-TD result is also in very good agreement with these results. For R = 1.43 Ω, the cut-off frequency (for 3 dB attenuation) is 6 MHz with the exact expression (4) and 10 MHz with the approximate expression (7). The FD-TD result gives a cut-off frequency of 7.8 MHz between the two previous values.

5. IN-FLIGHT EXPERIMENT MODELLING

In reference [1] when the current pulse simulating the negative leader mechanism is injected onto the aircraft by means the 3D computer code all the calculated fields are in good agreement with experimental results except the magnetic field computed in the fuselage, behind the carbon composite door.

The signal obtained (figure 8b) exhibits a first order low-pass filter response having a cut-off frequency of 9 kHz whereas the measured signal (figure 8a) exhibits a response with a 50 kHz cut-off frequency. It has been shown that the only possible path for this high frequency content is the joint located all around the door and used to pressure the aircraft: a joint of poor quality increases the penetration of electromagnetic energy and so increases the internal frequency content (see § 2). This joint resistance being unknown our purpose here is to calculate its value and then to introduce this value in the 3D code and compare the results to the experimental data.

When penetrating inside the fuselage the external magnetic field is:

- Attenuated by a geometrical effect. This attenuation (40 dB) has been evaluated using the 3D code and assuming the door is unloaded (figure 9).
- Filtered by the carbon composite material of the door. This filtering effect if given by the relations (4) and (6).

Knowing the values of F_c, a and Z_s, we can deduce from (6) the resistance R of the joint. In the case of the Transall experiment, we obtained $Z_s = 30\ m\Omega$, $a = 0.68\ m$ and $F_c = 50\ kHz$, so $R = 12\ m\Omega$.
These values of Z_s and R have been introduced in the code "ALICE" and the result is shown in figure 10. This response is in very good agreement with the in-flight measurement.

6. CONCLUSION

The goal of this paper is to present a formalism based on the sheet impedance concept which has been introduced in a 3D FD-TD code in order to take into account electromagnetic coupling through lossy materials and through resistive joints. The predictive capabilities of the code have been evaluated by comparison to analytical results obtained by K.F. Casey. The numerical tool has been used to model the penetration of electromagnetic fields through a carbon composite door located on the fuselage of an aircraft struck by lightning during an in-flight experiment. A very good agreement with in-flight measurements can be obtained if one takes into account the coupling through the joint surrounding the door.

REFERENCES

[1] Alliot, J.C.; Grando, J.; Muller, J.D.; Ferrières, X.: FD-TD numerical simulation of an entire lightning strike on the C160 aircraft. International Aerospace and Ground Conference on Lightning and Static Electricity, Cocoa Beach, Florida (USA) (April 16-19 1991).

[2] Casey, K.F.: Low frequency electromagnetic penetration of loaded apertures. IEEE Trans. on EMC, Vol. 23, No 4, (November 1981).

[3] Moreau, J.P.; Jouan, J.Y.; Issac, F.: Transall 88 characterization program. Proceedings of ICOLSE Conference, Bath (UK) (Sept. 26-28 1989).

[4] Gobin, V.; Aparicio, J.P.; Grando, J.; Alliot, J.C.: The surface impedance: a pertinent parameter to describe finite conductivity materials in numerical codes. Paper proposed to EMC, Zurich (1991).

[5] Grando, J.; Issac, F.; Labaune, G.; Alliot J.C.; Ferrières, X.: Field penetration through composite material using FD-TD method. 1990 IEEE AP-S International Symposium and URSI National Radio Science Meeting, Dallas (Texas) (6-11 May 1990).

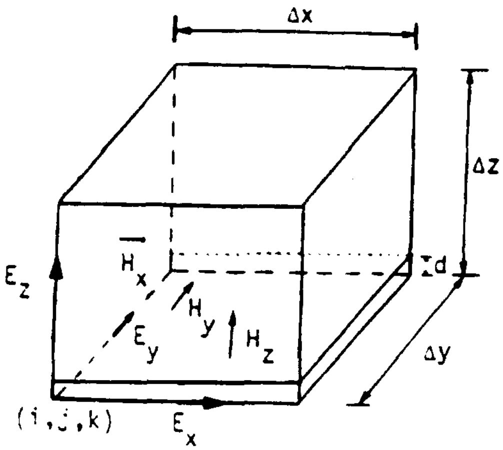


Figure 1 : Elementary cell with a composite material (ε,σ,d).

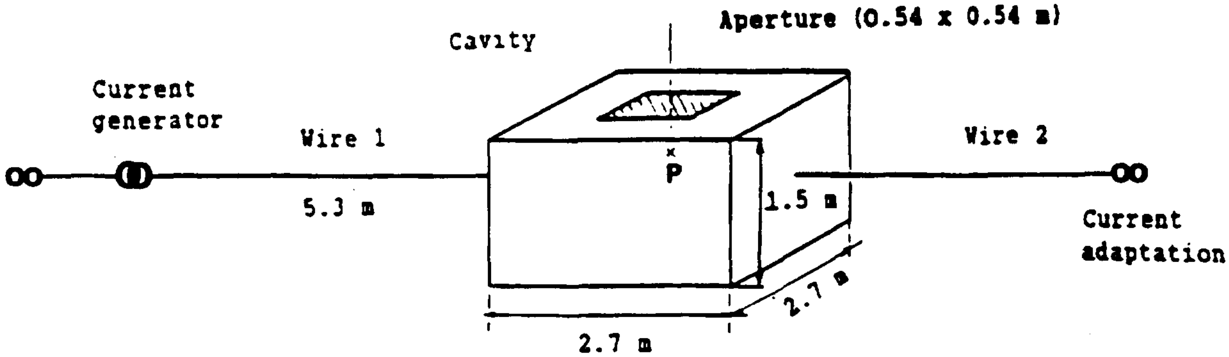
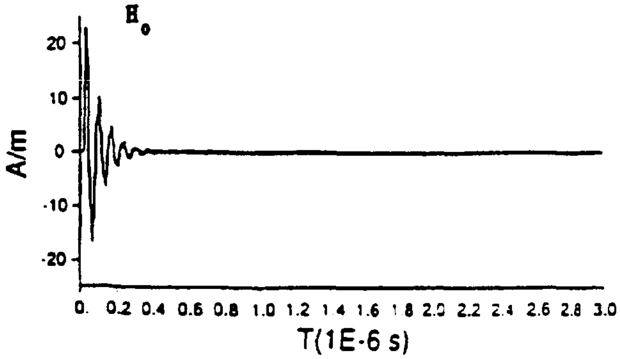


Figure 2 : Structure used to calculate field penetration through a loaded aperture.



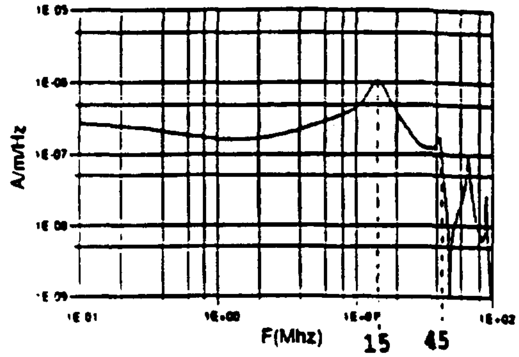
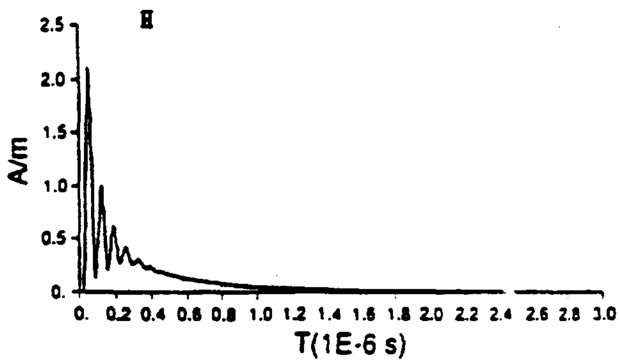


Figure 3a : Waveform of the magnetic component at point P. (free aperture)

Figure 3b : FFT of H_o component.



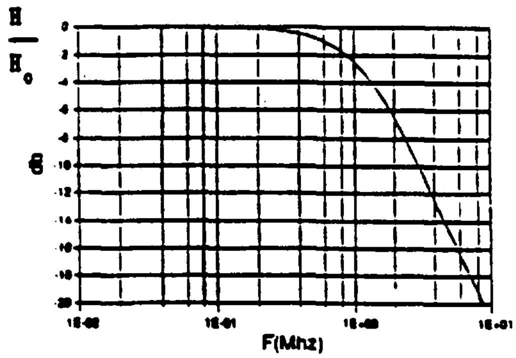
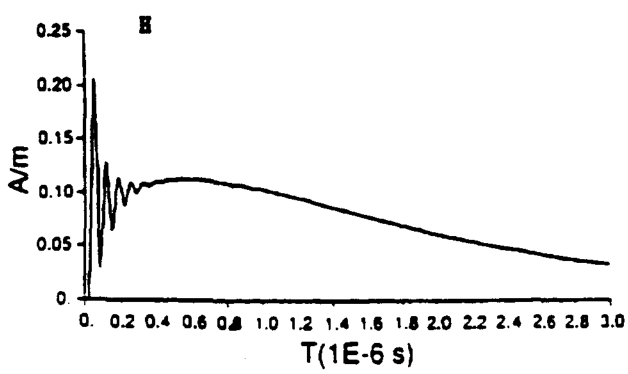


Figure 4a : Waveform of the magnetic component at point P. (loaded aperture $Z_s = 1\ \Omega$)

Figure 4b : H and H_o FFT ratio.



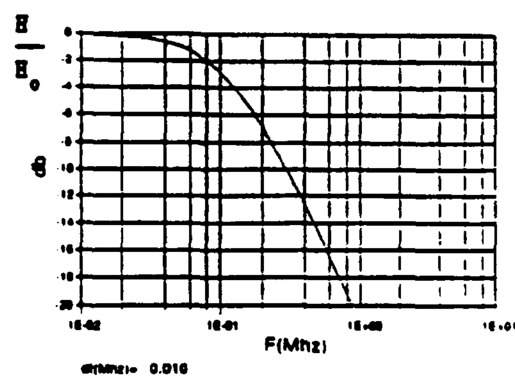


Figure 5a : Waveform of the magnetic component at point P. (loaded aperture $Z_s = 0.1\ \Omega$)

Figure 5b : H and H_o FFT ratio.

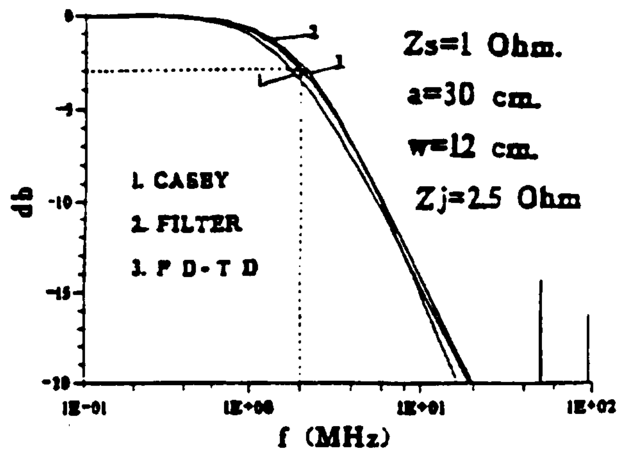


Figure 6 : Magnetic field attenuation for a composite panel (Z_s = 1 Ω) with a net contact resistance R = 0.16 Ω.

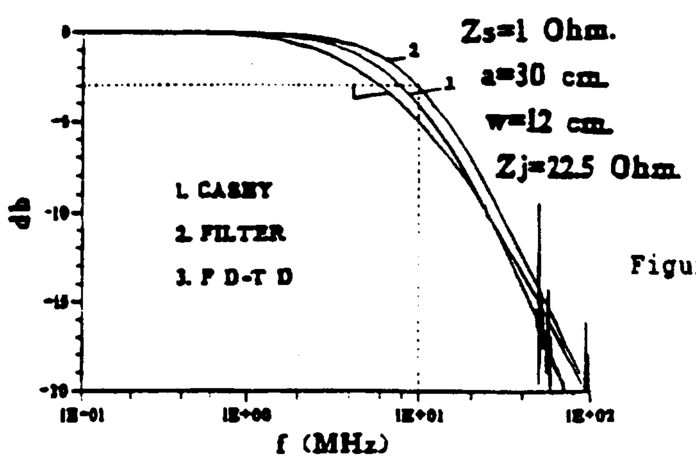


Figure 7 : Magnetic field attenuation for a composite panel (Z_s = 1 Ω) with a net contact resistance R = 1.43 Ω.

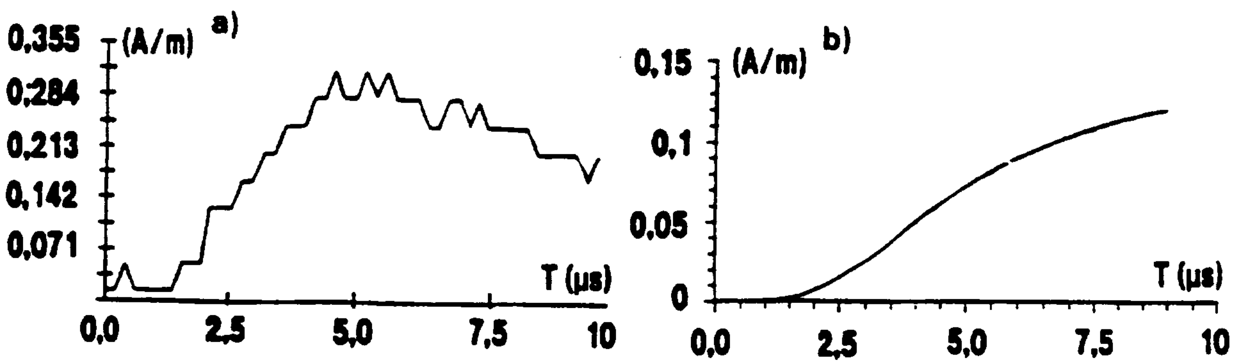


Figure 8 : Internal magnetic field.

a) Measured during in-flight experiment.
b) Calculated without taking into account the joint resistance.

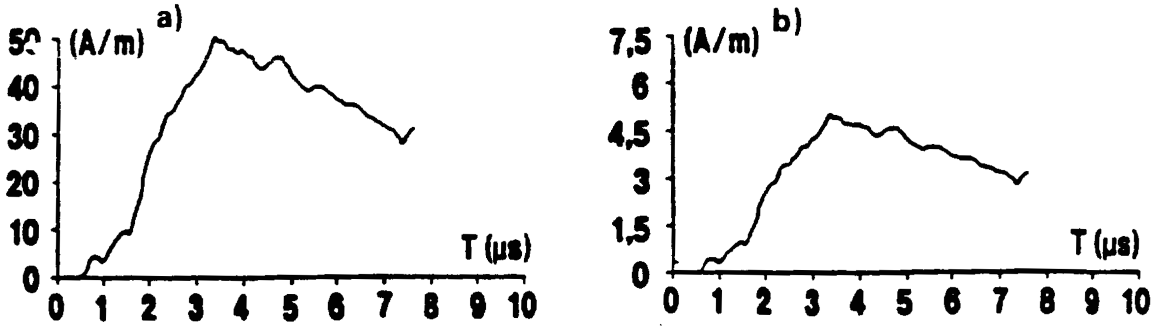


Figure 9 : Calculated magnetic fields.

a) On the external skin of the fuselage near the composite door.
b) Inside the fuselage assuming the door unloaded.

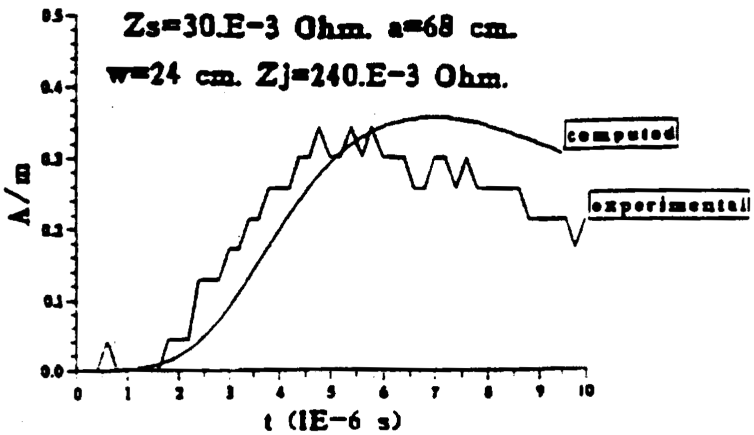


Figure 10 : Magnetic field amplitude behind the composite door of the aircraft.